Thermal instability of gas desorption due to plasma-wall interactions

Sergei Krasheninnikov

University of California at San Diego, USA

PFC Meeting

San Diego, February 28, 2006

- In [S. I. Krasheninnikov, INTOR, USSR Contributions to the Phase IIa, IAEA, Vienna, December 1985] it was shown the interactions of plasma with tokamak plasma-facing components saturated with hydrogen can be unstable against perturbations of wall temperature T_W

- The physics of this instability is related to the positive loop associated with an increase in neutral desorbing rate with increasing T_W and the further increase of wall temperature caused by an increase of heat flux to the wall resulting from the corresponding charge exchange neutrals and enhanced plasma flux to the wall

- It is plausible that such thermal instability may explain the some recent results from long pulse dischargers (e. g. formation of MARFE in JT-60 [IAEA-2004, Papers IAEA-CN-116/OV/1-1and IAEA-CN-116/EX/10-3]
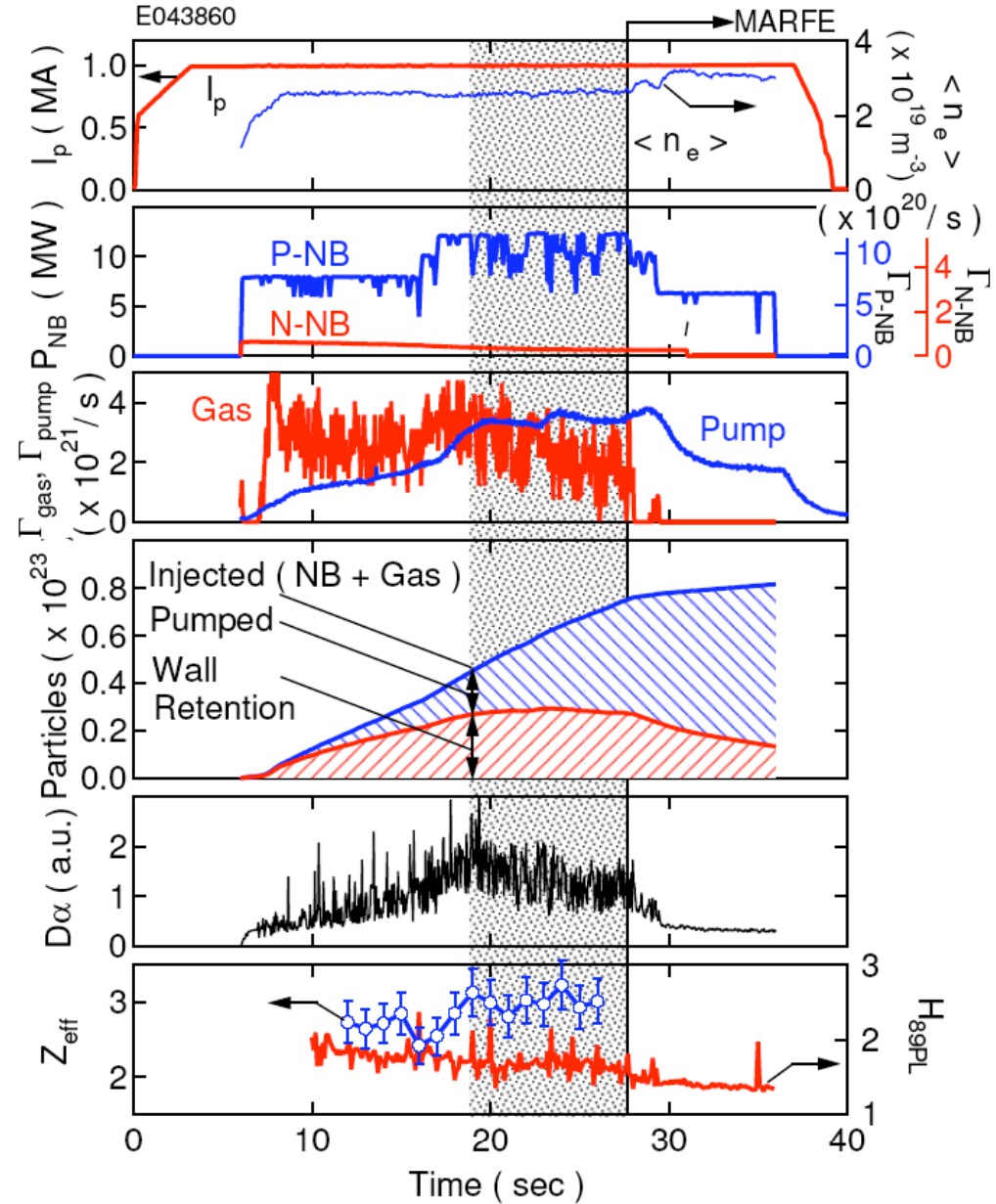
- It is also possible that such thermal instability may trigger some "unexplained" disruptions (recall that during disruption plasma density increases strongly due to wall desorption, [see for example Hollmann et al., PoP **10** (2003) 2863])

- To estimate the growthrate of such instability we use 0-D model describing the balance of particles, energy as well as the wall heat balance

- We consider the equations governing the wall temperature, T_W, tokamak plasma density, n, and effective plasma energy, W

$$\frac{dT_w}{dt} = \frac{W}{\tau_E} + n^2 K_{rad} - \frac{T_w}{\tau_w}, \tag{1}$$

$$\frac{dn}{dt} = -\frac{n}{\tau_n} + \frac{N-n}{\tau_D} \exp\left(-\frac{\Delta E}{T_w}\right), \tag{2}$$

$$\frac{dW}{dt} = P - \frac{W}{\tau_E} - n^2 K_{rad}. \tag{3}$$

where $\tau_{(...)}$ are the effective equilibration time scales; P is the hearing power; N is the effective total number of hydrogen atoms in tokamak (including wall); K_{rad} describes both radiation and charge-exchange energy loss, ΔE is the hydrogen desorption activation energy

- Assuming that all $\tau_{(\ldots)}$ as well as K_{rad} are constants, from Eq. (1-3) we find the equation for the growthrate γ

$$\left(\gamma + \frac{1}{\tau_w}\right)\left(\gamma + \frac{1}{\tau_E}\right)\left(\gamma + \frac{1}{\xi_{wall}\tau_n}\right) = 2\xi_{rad}\frac{\Delta E}{T_w}\frac{\gamma}{\tau_n\tau_E}, \qquad (4)$$

where ξ_{wall} is the wall fraction of total amount of hydrogen, and ξ_{rad} is the rad & charge exch fraction in the overall W loss

- Instability with the growthrate $\sim \gamma_0$ (hard excitation!) exist where

$$\gamma_0 \equiv \left(\frac{\Delta E}{T_w}\frac{2\xi_{rad}}{\tau_n\tau_E}\right)^{1/2} \quad > \quad \gamma_1 \equiv \frac{1}{\tau_w}, \quad \gamma_2 \equiv \frac{1}{\tau_E}, \quad \gamma_3 \equiv \frac{1}{\xi_{wall}\tau_n}. \quad (5)$$

- Taking into account that $\Delta E / T_w >> 1$, we find that for a saturated wall ($\xi_{wall} \approx 1$) and significant radiation loss ($\xi_{rad} \sim 1$) (recall JT-60 conditions) the expression (5) can be easily satisfied

- Moreover, stabilization of such thermal instability by pumping ($dn / dt = (...) + (n_0 - n) / \tau_{pp}$) is impossible (stabilization requires unrealistic pumping speed $\tau_{pp} < \tau_n$!)

- Crude estimate for JT-60 conditions gives time scale of thermal instability below 1sec, which does not contradict to experimental observations

Conclusions

- Interactions of plasma with saturated wall can cause thermal instability of wall temperature resulting in massive desorption of gas from the wall

- In can lead to the formation of MARFE or even disruption and can be crucial for a long pulse ITER operation

- Rather rudimentary theoretical model accounting for plasma-wall interactions and the heat balance of the wall predicts the time scale of such instability below 1 sec for JT-60 like tokamak

- More experimental data and more refined theory are needed!